LASER BONE INTERACTION, Comparative study between XeCl excimer laser and erbium: YAG laser

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Abstract:

These experiments aimed to investigate and compare the nature of the zone of secondary damage in calvarial bone defect prepared with either XeCl excimer laser or the erbium: YAG laser light at 75mJ/pulse. Material & Methods: These experiments were conducted in vitro, using excised calvarial bone, which was examined by environmental scanning electron microscopy (ESEM). Results: The excimer laser produced a morphologically different defect in bone. It was smooth surfaced with extensive scattering of debris and cracking. Were the Erbium: YAG laser slot showed less charring than XeCl excimer laser and the surface was smooth with microspheratic pattern. Energy dispersive x-ray analysis showed that the carbonisation and Ca/P ratio were higher in XeCl excimer laser defects compared to erbium: YAG laser defects.

Key words. Bone, ESEM, x-ray, carbonisation, Calcium, Phosphate, laser.

INTRODUCTION

The laser induced effect on the biological tissue depends on the output Power, the energy density of the laser irradiation, the wavelength of the emitted light and the mode of the laser device (continuous or pulsed) (1). Previous studies have shown that laser ablation of bone is associated with secondary damage to the tissue Surrounding the prepared defect (2). The extent of the secondary damage is variable and depends on the laser type and energy. Erbium: YAG lasers light tend to produce narrower zones of damage in bone than Holmium: YAG lasers light in vitro (3). The bone composition and state of hydration also appear to be important variables (4). The excimer laser light ablates bone through "photodecomposition", which is a term that was first introduced by Srinivasan in the early 1980s(5). Excimer laser have a wavelength range between 351-193nm with pulse duration of nanoseconds. The shorter the wavelength the more efficient is the ablative process. Calvarial bone in vivo is a composite of mineralised and unmineralised matrix, cells, vessels and marrow. The latter often being rich in lipid-laden adipocytes. All of these elements may react differently to laser energy, and their degradation is likely to result in carbonisation and exposure of bone minerals.

MATERIALS AND METHODS

Three mature Sprague-Dawley rats were killed and the calvariae removed and used immediately. The pulsed erbium: YAG laser beam was applied to the calvariae. One slot was prepared in the outer surface of each side of the calvariae using the erbium: YAG laser light at 75mJ per pulse with a lens of 50mm focal length giving a fluence of 38J/cm^2. All the slots were prepared with the bone hydrated at all times with generous saline coolant applied during the lasing procedure. A further three mature rats were killed and the calvariae removed and used immediately. Two slots were prepared in each calvariae, one on each side using a Xenon Chloride (XeCl) excimer laser light, at a wavelength of 308nm. The pulse energy was set to 75mJ per pulse, at a repetition rate of 15Hz. The output was focussed using a 10cm focal length silica lens. The six calvariae were then examined immediately, without coating or drying in an electroscan E3 environmental scanning electron microscope (Wilmington, DE). RESULTS

Microanalysis of the specimens was carried out to detect the presence of carbon in particular and the calcium and phosphate using x-ray analysis. The x-ray spectrometer collects the characteristic x-ray. The spectrometer counts and sorts the x-ray, usually on basis of energy. The resulting spectrum analysis (EDAX) plots number of x-ray on the vertical axis, versus energy on the horizontal axis. Peaks on the spectrum correspond to elements present in the sample. Using an ISIS system coupled to an atmosphere thin window detector (Oxford Instruments Microanalysis Group, High Wycombe, UK). Specimens were examined at 8*C and 6.4 torr, using accelerating voltage of 20kv. The specimens were analysis in the ESEM. The x-ray spectrometer displayed peaks at energies characteristic of elements present in the sample. Calculation of the peak to base ratio of carbon, phosphate and calcium was carried out and the calcium phosphate ratio was obtained.

Environmental Scanning Electron Microscope studies

The specimens that received 75mJ/pulse with the erbium: YAG laser light showed well defined slots with less charring than the specimens that received 75mJ/pulse with the excimer laser. With the erbium: YAG laser there was a smooth surface with raised plaques that appeared to have incorporated some microspheritic bone mineral. Pools of putative lipid flowed out under ESEM conditions (Fig 1). Bone cracking and a microspheritic pattern were seen at most of the slot (Fig 2).

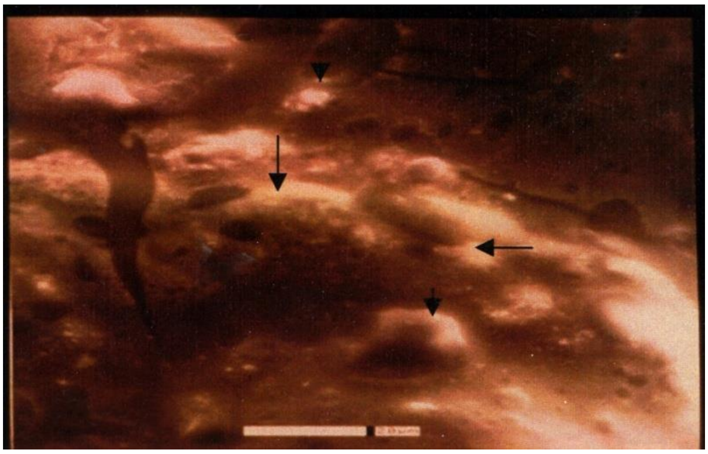

Figure1

Figure 1. Lased calvarial defect examined under hydrated conditions using ESEM. A smooth surface, with encrusted mineral microspheres (arrows) surrounded by lipid fluid. (mag x 385).

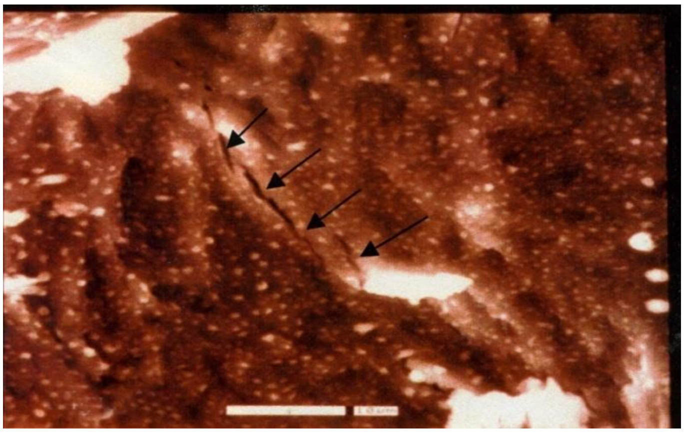

Figure2

Figure 2. Laser calvarial defect examined under hydrated conditions using ESEM. Showing a bone crack (arrows) and the microspheritic pattern of the surrounding bone. (mag x 250).

When the laser pulse hits the bone surface, it causes ejection of the inorganic material to the edges of the slot. This results in an increased concentration of these materials at the crater edges. The specimens that received 75mJ/pulse XeCl excimer laser light at a 308-nm wavelength showed a yellow discoloration zone around the lased bone slots. The width of the damaged zone depended on the nature of the irradiation, the number of pulses and the output power. With the ESEM, the specimens showed a smeared smooth surface defect. The cutting surface was smooth, with collagen fibres covered by calcified material (Fig 3). The defect was covered by a very minute calcified particles (dust like debris) scattered all over the defect. The specimens also showed horizontal cracks and haversian system (Fig 4). No signs of any damage were seen in the area not immediately adjacent to the ablated zone.

Figure3

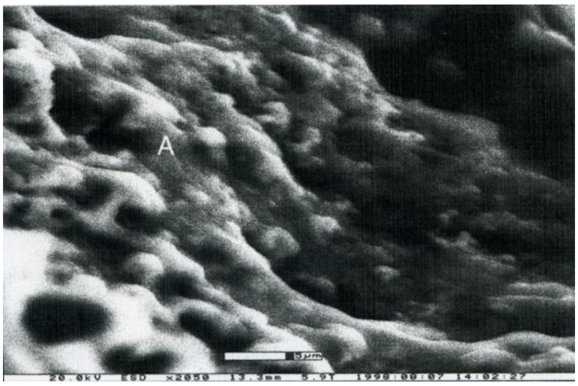

Figure 3. Lased calvarial defect created by excimer laser examined under ESEM, showing a smooth surface with collagen fibers covered by calcified materials (A). (mag x 2050).

Figure4

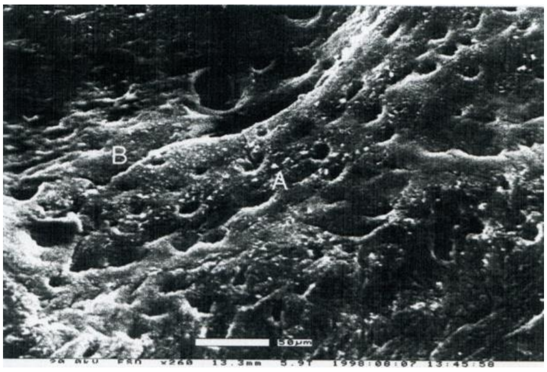

Figure 4. Lased calvarial defect created by excimer laser examined under ESEM,

showing dust like debris (A) and horizontal cracks (B). (mag x 260).

CHEMICAL ANALYSIS BY EDAX. (Energy Dispersive X-ray Analysis).

The EDAX displays the peak energies characteristic of elements present in the sample. Calculation of the peak to base ratio for carbon, Phosphate and calcium was carried out for every chart. The numbers generated by the computer were used to calculate the peak to base ratio of carbon, phosphate and calcium. The mean peak to base ratio of C: P: Ca for the slot prepared with 75mJ/pulse XeCl excimer laser light was 1.22: 2.87: 6.47 and the mean of Ca to P ratio were 2.27. Also the peak to base ratio of C: P: Ca in the slots prepared with the 75mJ/pulse erbium: YAG laser light was also calculated. The mean peak to base ratio of C: P: Ca was 0.09: 2.2: 4.69 and the mean Ca to P ratio was 2.14 as shown in table (1)

Type of laser	Peak/base ratio of C:P:Ca	Ca/P	%of C:P:Ca
Erbium:YAG 75mJ/p	0.5:1.7:3.9	2.29	2.7%,33.9%,63.4%
	0.008:2.3:4.8	2.08	0.0%,34.1%,65.9%
	-0.02:2.3:4.6	2	-0.1%,35.7%,64.3%
	-0.04:2.4:4.8	2	-0.1%,35.2%,64.8%
	0.09:1.9:4.2	2.21	0.1%,22.1%,77.8%
	0.06:2.4:5.1	2.12	0.1%,32.4%,67.7%
	0.007:2.4:5.4	2.25	0.0%,24.6%,75.4%
Mean	0.09:2.2:4.69	2.14	
Excimer 75mJ/p	1.03:2.9:5.7	1.96	2.0%,33.0%,65.0%
	1.24:2.3:6.3	2.74	2.1%,31.5%,66.4%
	1.16:2.9:6.7	2.31	1.1%,26.0%,72.8%
	1.4:3.2:7.2	2.25	1.5%,29.7%,68.7%
	1.4:2.6:6.6	2.54	1.8%,31.5%,66.7%
	1.1:3.3:6.3	1.9	1.9%,34.4%,63.8%
Mean	1.22:2.87:6.47	2.27	

Table (1), shows the power setting of the erbium: YAG and excimer laser used and the calculated peak to base ratio of C: P: Ca and Ca/P (original raw data not shown).

DISCUSSION

Tissue carmelisation, carbonisation, vaporisation, micro-explosion, fragment ejection, molecular disruption and plasma formation are all recognised as photothermal ablation mechanisms. They are associated generally with increasing tissue temperatures produced by the manipulation of the laser parameters, especially power density and exposure time(6).

Choosing special irradiation parameters is critical for the production of a clean cut lesion. Also addition of water spray during ablation significantly improves the performance of laser both in terms of ablation efficiency and reduction of side effects(7). The slot prepared with XeCl excimer laser at 75mJ/pulse scored higher carbon as compared to the slot prepared with erbium: YAG laser at 75mJ/pulse, the former scored an average of 1.22 and the latter scored 0.095. The EDAX analysis showed a well defined peak of carbon with XeCl excimer

laser as compared with the erbium: YAG laser. This result verified the results found by Isner et al; that the ablative photodecomposition with the 308-nm wavelength laser was accompanied by noticeable thermal damage(8). As the XeCl excimer laser was photo-thermal, we expect a higher carbon score as shown in the table (1). Electron microscopy of bone reveals islands of mineralised filaments surrounding collagen fibres. X-ray microanalysis findings and the Ca/P ratio are consistent with the interpretation that intact constituent mineralised microspheres remain upon the surface after lasing. In the intact normal bone, little variation has been previously reported in the calcium and phosphate concentration in different regions of the same bone(9). The erbium: YAG laser and the excimer laser both produce high concentration of calcium and phosphate at the cutting edges (Ca/P=2.28 after excimer laser and Ca/P =2.14 after erbium: YAG laser), compared to the normal bone, where the calcium to phosphate ratio was determined as (1.656) in normal bone specimens. The molar Ca/P ratio of the theoretical formula of all complete apatites is 1.666+. Brown, reported that the Ca/P ratio was lower than 1.6 in apatites(10). As the laser energy increases the Ca/P ratio increases; on the other hand the carbon level decreases. The precise mechanism for this is not clear. It may be due to calcium precipitation from cellular components or alteration in mineral composition. Many factors contribute to the Ca/P ratio as the age of the animal, dietary mineral alteration and physiological and pathological variables. The average peak to base ratio of C: P: Ca was 0.095: 2.2: 4.69 in the slots prepared with erbium: YAG laser light, where it was 1.22: 2.87: 6.47 in the slots prepared with XeCl excimer laser light. From this results and the literature we suggest that excimer lasers presently in use are not suitable for bone surgery. The photoacoustic damage produced by 193nm excimer laser(11), and the low ablation rate of the 308nm excimer laser(12), limits their clinical use in bone. Also bone debris produced after 308nm excimer laser, may act as a foreign body and delay the healing. Further studies are required to examine the thermal effect and the acoustic stress generated by excimer lasers.

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